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PRECISION AGRICULTURE: REALIZING INCREASED PROFIT AND REDUCED RISK THROUGH COST MAP AND LIGHTBAR ADOPTION

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ABSTRACT OF THESIS

PRECISION AGRICULTURE: REALIZING INCREASED PROFIT AND REDUCED RISK THROUGH COST MAP AND LIGHTBAR ADOPTION

This thesis examines the use of two specific types of precision agriculture technologies: cost maps and lightbar. Cost maps visually depict spatial differences in production costs. The visual depictions of these costs are represented using ArcGIS in an attempt to aide farmers in further decision making. Results will show that cost maps have great possibilities in their addition to the set of tools that farmers use in decision making. This thesis will expand the understanding of lightbar from a partial budget study to a whole farm model incorporating competition across different enterprises for labor and capital. The results from the study of cost maps indicate that inaccuracy of machinery movement, whether in the application stage or the harvesting stage is very costly. As a result, the suggestion of lightbar as a guidance aide to improve farm profitability is recommended under the conditions analyzed and shows a net farm return increase in just over 6%.

KEY WORDS: Precision Agriculture, Lightbar, Cost Maps, Whole Farm Model, ArcGIS

____Benjamin Michael Kayrouz____

___________May 12, 2008__________

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THESIS

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The Graduate School

University of Kentucky

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PRECISION AGRICULTURE: REALIZING INCREASED PROFIT AND REDUCED RISK THROUGH COST MAP AND LIGHTBAR ADOPTION

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
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at the University of Kentucky

By

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Lexington, Kentucky

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2008

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"Many hands make light work." This quote from John Heywood not only refers to manual labor, but encompasses work in general. The completion of this thesis has not been the work of one individual, but the combined effort of many. Without the help of my teachers, family and friends, this thesis would never have come to fruition.

First and foremost, I would like to acknowledge the influence that God has had on this thesis. Being a constant in my everyday life, God has granted me the knowledge, understanding and perseverance that was necessary to complete a goal of this size. He was present throughout my endeavor in the form of those near to me. My committee members, family, and friends were nothing but supportive through the past two years with positive comments, insights, and information: they were the many hands that made this work light.

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Economics department, for agreeing to be a committee member, while having limited prior encounters between himself and I.

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Dr. Dillon says "If I surround myself with good and smart people, they make me look good and smart". I have been fortunate to have my classmates and peers Jordan and Ryan as those smart students. I thank them for their friendship and influence.

It has been the combined efforts of all these people and more that have made this thesis a reality. With the many hands of God, my professors, family and friends, this truly has been light work.

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Chapter One

Introduction

1.1 Introduction

New opportunities and choices to make are brought before farmers every day. The goal of the farmer is to decide which of these opportunities will increase farm profitability as well as reduce risk. In the early 1900's, farmers were being introduced to the idea of tractors, whose initial efficiency on farms was still being decided. Applications which used the potential of tractors came only after users and manufacturers acquired experience with the new technology (Lowenberg-DeBoer, 1996). The idea that it takes time and effort to realize the full potential of a concept is not new and is tested throughout this thesis.

The study of precision agriculture and farm management practices will be the recurring theme throughout this thesis. Precision agriculture can be described as information technology applied to agriculture. Farmers have always known that certain parts of a field produce differently than others, but until precision agriculture came along, farmers lacked the technology to apply this knowledge. The basis of precision agriculture is that it allows the study of fields on a much finer resolution. This in turn provides opportunities for higher yields and/or lower costs. Farm producers may have the opportunity to optimize production outputs with the application of technologies of precision agriculture. Two separate technologies are studied in this thesis: Cost Maps and Lightbar. The goal of the research is to analyze the application of cost maps and lightbar with the desired result of increasing net returns while decreasing risks.

The analysis of cost maps shows with a visual depiction that overlaps, misses, and reapplication of inputs to certain areas of a field may cost farmers more then they previously thought. The suggestion is to use guidance aides such as lightbar to help reduce these costs. Lightbar, which is not a relatively new topic in precision agriculture, is primarily studied from a partial budget approach. The partial budget is a commonly used decision-making tool, which looks at incremental changes in the farm business (Forster and Erven, 1981). This thesis extends previous partial budget studies into a whole farm model evaluation of lightbar and takes into consideration all costs, as well as competition across enterprises for labor and capital. Both studies assess the relevance of individual precision agriculture technologies and their implications.

1.2 Objectives of this Study

The objective of this study is to assess precision agriculture management practices to improve farm profitability as well as reduce risk, specifically, the practices of Cost Maps and Lightbar. Each practice is written as an individual article that is relevant to precision agriculture but represents a self contained paper. This is referred to as a 'multiple journal article' approach. The approach to a thesis with multiple journal articles provides more opportunities to the writer. After the completion of one manuscript, attempts can be made to publish the work while still continuing on the other manuscript. This not only allows the writer to work more fluidly but also allows introduction into the world of publications and conferences. This approach however, does present the potential for repetition between chapters.

When deciding how much output to produce a farmer will consider where marginal revenue equals marginal costs. Farmers have been able to study marginal revenue in precision agriculture with the aid of yield maps and have begun to evaluate marginal costs by looking at single inputs. An example of a single input may be fertilizer. While yield is a good representative of marginal revenue, a single input such as fertilizer alone is not complete enough to comprehensively evaluate marginal costs. To be more inclusive other variables such as labor, machinery repair, and fuel input need to be included. With consideration of these additional variables a more complete assessment of marginal costs is available to farmers. This increases the accuracy in which the farmer is able to equate marginal revenue to marginal costs.

The objective of Chapter 2 is three-fold. The first objective is to develop spatial production cost maps. The second objective is to demonstrate the utility of production cost maps using empirical input functions. The third objective is to discuss the potential uses of production cost maps. Suggestions for management opportunities in this chapter include to the use of guidance aides such as lightbar.

The technology of lightbar has been applied and analyzed under enterprise partial budgets and has demonstrated to be profitable. Expanding the study of lightbar technology to the whole farm is the next logical step for evaluation. This expansion in Chapter 3 takes into consideration interactions between different enterprises of single cropped soybeans, corn, wheat and double cropped soybeans and wheat including the competition across enterprises for land, labor, and capital. The most profitable combination of competitive enterprises can be determined by comparing the output substitution ratio and the output price ratio. With a whole farm study, the comparison between the output substitution ratio and the output price ratio reflects the most profitable combination of competitive enterprises allowing for selection of variable planting dates and enterprise mixes. This improves on the partial budgeting framework of lightbar where changes of production practices or dates do not encompass all the costs/benefits of lightbar. The objective of Chapter 3 is to expand the partial budget framework of lightbar analysis into a whole farm planning approach, which will take into account interactions between different enterprises. This will include the competition across enterprises for land, labor, and capital. With lightbar becoming more prevalent in the Ohio Valley region, farmers need to see statistics on how it can affect them, and their whole farm. Partial budgeting does not take into consideration all the costs/benefits that lightbar has to offer and therefore does not give a complete understanding. With this study the costs and benefits of lightbar will be evaluated for farmers of all types and sizes.

Chapter Two

Production Cost Maps as a Tool for Improved Farm Management

2.1 <u>Introduction</u>

Technology is constantly evolving with respect to production agriculture. Precision farming technologies have been increasingly recognized for their potential ability for improving agricultural productivity, reducing production cost, and minimizing damage to the environment (Zhang et al., 1999). Advances in machinery that include the ability to accumulate detailed crop production data and advances in analytical tools to distill these data into performance metrics are changing the way these businesses are managed. For many years, farmers have benefited from the use of yield monitoring data in making management decisions. Since the late 1980s, technology for yield monitoring and accurate positioning has been available with the expansion of application since the early 1990's (Cook and Bramley, 1998). The basis of precision agriculture is the opportunity yield monitoring affords in the provision of spatially detailed information in management when coupled with appropriate methods and analysis. One could simply say this is essentially the application of information technology to agriculture. Relevant expansion of yield maps includes the concept of creating net returns maps to provide an economic perspective to spatial data. What seems to be lacking is a reflection of detailed cost differentials. While spatially dependent cost data associated with variable-rate management of crop production inputs may be considered, differences in machinery operating costs and operating capital costs across the field are generally not depicted in these maps. This study focuses on the usefulness of analyzing variable costs associated with production.

The targeted area for this research will be to identify the usefulness, importance, and relevance of spatial production cost maps as another tool to guide producers in achieving optimal profitability. Specifically, there are three objectives: 1) to develop spatial production cost maps, 2) to demonstrate the utility of production cost maps using empirical input functions, and 3) to discuss the potential uses of production cost maps.

The study will include typical farms from Western Kentucky and will also apply to farms of various soil landscapes. Machinery operating costs will vary in accordance with the spatial variation in ground speed and field efficiency, which are major factors in machinery operating costs. For example, slowing down a tractor when making turns or speeding up a combine in areas of low yields results in the spatial variation of fuel, labor, and other machinery operating expenses. Ultimately, these variations will be reflected in the production cost maps, and subsequently, more accurate net returns maps will be possible.

2.2 Background Information and Literature Review

With the advances of technology and a fast paced economy, precision agriculture is on the forefront of farming. Precision agriculture may be viewed as site specific crop management. Cook and Bramley (1998) refer to precision agriculture as crop management methods which recognize and manage spatial and temporal variations in the soil-plant-atmosphere system with the objective of improving control of input variables to increase profitability, reduce environmental risk and improve product quality. The practice of precision agriculture may be viewed as four stages of information acquisition, interpretation, evaluation, and control (Cook and Bramley, 1998). This four-stage cycle of precision agriculture begins with data collection. Variable inputs are applied in field operations which are then interpreted and evaluated with respect to economic and environmental impacts. This evaluation becomes a part of the data collection process in subsequent years, refining the precision management plan. System and technological applications are essential for efficient data collection and analysis.

Yield mapping is one application of data analysis where the process of observation, interpretation, evaluation and implementation can be applied. “The yield map intensifies observation, but benefit follows implementation which can only improve after the observation has been interpreted and evaluated by the decision maker” (Cook and Bramley, p. 754, 1998). Interpretation describes the perceived likelihood of possible events, given information contained within the map. The decision maker evaluates the likelihood of alternative outcomes to determine if an alternative decision or action should be implemented. Although yield mapping provides valuable information pertaining to marginal revenue, a complimentary analysis of marginal cost needs to occur. Marginal revenue and marginal cost may be affected by uncontrollable risks.

Reduction in government price supports, weather variability, and other uncontrollable environmental factors such as insect and disease infestation contribute to the increased concern of risk management. It is hypothesized by Lowenberg-DeBoer (1999) that precision agriculture technologies are useful in risk reduction. The application of such technologies provides producers with more and better information and increased control of crop growing conditions. Lowenberg-DeBoer focused on site specific treatment of problem areas to reduce the probability of low yield and returns. Empirical evidence was provided to support the hypothesis. He further concluded that “empirical work, especially on-farm trials, is needed to determine the potential for widespread risk management benefits from precision agriculture technology." (p. 284, 1999)

Companies new and old are investing time and money into precision agriculture technology products and tools. As a result, markets have shown a decrease in price and an abundance of precision agriculture hardware. Farmers are constantly bombarded with articles and advertisements that show the benefits of different applications where precision agriculture has been implemented. With all these tools at reasonable prices, precision agriculture hardware sounds like an easy purchase, but there is more to precision agriculture than just buying the tools. Along with economic theory, farm management techniques need to be applied before the tools of precision agriculture can be evaluated for profitability.

Site specific application of agricultural technology and inputs may be implemented by dividing the field into smaller management zones. A management zone is defined as a portion of the field differentiated from the rest for the purpose of receiving specific inputs and management attention (Kvien and Pocknee, 2006). By this definition, different management zones may exist for different input purposes and analysis. There are no set rules or processes for the establishment of management zones. Zones are not solely functions of the field's physical properties, but may also be a function of the input (Kvien and Pocknee, 2006). The quality of the zones will depend on the skills and resources available and the nature of the field being mapped. If there are insufficient skills or tools available, or if the field is complex, the utilization of management zones may not be effective. One simplistic approach would be to begin by defining areas that would obviously benefit from differential management. After identification of this area, one could establish yield goals for the zone. Inputs and technology can be applied to the mapped area with yield analysis. Monitoring the performance of the individual zones over time can foster an understanding of the dynamics of the inputs and allow for modifications or replications of the process to other similar zones.

Because cropland is not spatially homogenous, precision farming techniques of sampling, mapping, analysis, and management of production areas with recognition to spatial variability is necessary and beneficial. Obtaining and applying spatially refined information presents a farmer with potential cost benefits. For example, the spatial character of the field may vary within an existing mapped area. This may result in a varied fertilizer application, variations in labor, fuel requirements, and other variable costs. Considering spatial differences, there may be the ability to control some of the cost variances by calculating areas of efficient applications as compared to areas of less efficient applications. Forecasting the effect of increased adaptation and technological advances or approaches on the cost of realized application surfaces is a task that is yet to be elaborated (Weiss, 1996). In spatial machinery costs research is also a vital tool for farm management. Traditionally, farmers have projected machinery costs based on total field application needs. The application of spatial machinery costs would allow for detailed data. That detailed data contains within it an approximation of a thorough section by section analysis. Now, instead of associating the aggregate cost of operations with a certain field, these costs can be depicted spatially as defined polygons.

Similar, but not equivalent, research has been devoted to the field of spatial data. Many of these studies have focused on analyzing data associated with yield as well as field efficiency. A paper written by Zhang and Taylor (2002) describes field efficiency as accounting for "a failure to use the theoretical working width of a machine, operator habits, turning time, and field characteristics" (p.887). Their objective was to use differential global positioning system (DGPS) data to evaluate the potential for improving harvest efficiency and capacity. With spatial cost in mind, these researchers were striving to improve field efficiency. Conclusions from their research suggested optimal field traffic patterns were a key to increasing field efficiency. The idea for an optimal path to increase field efficiency is an underlying idea of this papers' research, as well.

Where past studies focused mainly on the field efficiency as well as yield implications, this study looks at the cost implications of the data. Costs are associated with every aspect of farming, and with the technology available today, those costs can now be presented in the form of a color coordinated map. The maps are a fast and effective way to present a large amount of data in an understandable manor.

Geographical information system (GIS) software allows for computer mapping of inputs. A GIS is a set of computer tools that allows one to work with data that are tied to a particular location or spatially mapped area on the earth. A GIS is a database that is specifically designed to work with map data (Price, 2006). This allows for multiple detailed data to be graphically depicted on a map and utilized for decision making. Farmers have long since utilized maps for data collection and decision making. However, the difference with applying the advanced technology of GIS is that the GIS map exhibits "intelligence" where you can ask a question and get an answer. GIS technology application is influencing decision making because it avoids the shortcomings of traditional maps, allows for the rapid computer analysis, and applies sophisticated data structures. GIS technology application also efficiently represents the vastly comprehensive detailed environment (Kennedy, 2006). There are many GIS applications available for agricultural use. ArcGIS is developed and marketed by Environmental System Research Institute, Inc. (ESRI). ArcGIS is the application that is used to evaluate data for this study. As with most computer applications, improvements and enhancements to the program are embodied in new versions. GIS is possibly in the infancy stage of being accepted from a business application.

The term risk refers to the variability of the outcomes of some uncertain activity. The development of risk maps allow for a visual depiction of predicted risks. Incorporating risk maps into the decision making process allows for identification and management of problem areas or a comparison of production areas. Management of risk may directly impact net returns.

A previous study using ArcGIS used collected data to develop and analyze risk maps. An initial focus on net returns map were presented, these maps were shown to be a profitable tool for farmers to use. "However, the positive net returns were found to not imply a lack of risk" (Powers, et al., 2003). Risk maps were generated to identify changes in temporal risk by combining yield monitor data with expenses. Parts of the risky field were suggested to be enrolled into the Conservation Reserve Program (CRP) as applicable.

Additional research utilizing risk maps has been presented to Kentucky farmers through the Kentucky Cooperative Extension Service. These risk maps, specifically E-V maps, of net returns considered areas of non production. These areas of non production were also recommended to be enrolled in the CRP program. Statistics were calculated for four risk aversion levels and found to have a tradeoff between net returns and risk. The tradeoff was found to be that when risk was decreased, expected net returns were also decreased. As producers became more averse to risk, more land was removed from production (Dillon, et al. 2007).

2.3 Material and Methods

During the 2006 cropping season, data was collected from a grain farm in Central Kentucky. The cooperating farmers, Mike, Bob and Jim Ellis of Worth and Dee Ellis Farm, have utilized some form of precision agriculture technology since 1995. Throughout the 12 year association of the Ellis Farm with the University of Kentucky the operators have been introduced to, and adopted, numerous precision agriculture technologies including: boundary mapping, grid soil sampling, yield monitoring, variable rate application (VRA) fertilizer and lime application, parallel tracking, and automated guidance. All of these technologies are utilized in their 2500 ha (6000 ac) grain operation. The fields which are small and irregularly shaped are a somewhat unique characteristic to Central Kentucky. The average field size in the Ellis operation is just over 10 ha (25 ac). When approached regarding the possibility of aiding in research associated with cost maps, the farm operators immediately assisted. Data was given on field 38 of the Ellis operation which is a 15.6 ha (38.5 ac) field located in Shelby County Kentucky.

The Ellis operation, with its well maintained record keeping system, was able to provide data on fertilizer, planter, yield and sprayer applications for multiple fields. This paper concentrates on the sprayer application data for field 38. The application was administered by a 1994 model AgChem RoGator 664 self-propelled sprayer with a 24 m

(80 ft) wide boom. This particular sprayer was equipped with KEE Technologies (KEE USA, Sioux Falls, South Dakota) ZYNX X15 Multi Functional Console and 30 channel Auto Section Control unit (Spray Electronic Control Unit). A total of 48 nozzle bodies, spaced 50 cm (20 in.) apart, were fitted to the spray boom. Each channel of the Spray ECU was mapped to one or more of the 48 nozzles through software and by hardwire on the machine to supply current for nozzle valve activation. The Spray ECU was also connected to the flow meter and hydraulic flow control valve at the pump to facilitate control of spray application rates. A Trimble Navigation, Ltd. (Sunnyvale, California) AG 132 Differential Global Positioning System (DGPS) receiver with U.S Coast Guard radio beacon correction was utilized to obtain positioning information at a rate of 5 Hz for input to the ZYNX system. The radio beacon tower was located less than 40 km (25 mi.) from the farm thereby insuring sub-meter horizontal accuracy for most field data collection activities, which relates to a high level of accuracy (Shearer et al., 2006). Figure 2.1 shows the sprayer and modifications applied.

Data collected are stored in ASCII format on individual lines with corresponding geographic coordinate pairs in a Universal Transverse Mercator (UTM) projection. These data files were imported as text files into an Excel spreadsheet for analysis. After transferring the data into Excel the first step was to convert the GPS seconds into the change of seconds from one point to the other. Data collected from the sprayer indicated when the machines nozzles were turned off by a discontinuity of logged data. These discontinuities in the data, which indicate non-application, were assumed to be the turning of the machine at the end or a row or maneuvering around an obstacle in the field. Although the machine was not applying during those times, it was still accruing variable costs in the form of labor, fuel, maintenance, and lubrication. Sensitive to the fact the variables still needed to be accounted for, the change in time from the end of one row to the beginning of the next was divided by the number of observations from the previous pass and distributed equally to each point's initial change in seconds. This redistribution of time encompasses the whole aspect of variable costs associated with the sprayer.

The second step to be addressed was that of determining how much input at each given point was being applied. To do this, calculations were made to convert a 30-bit binary value which communicates the state ("on" or "off") of each sprayer channel into workable data. This data was then used to calculate how much area of application each channel covered for a given point. The area, combined with the input price of glyphosphate, was then related to the variable cost associated with the input. Input prices were set at a base price of US$7.74 with an application rate of 1.76 liter ha^{-1}.

The next step, was to take into account the variable costs associated with labor, fuel, maintenance, and lubrication. These data were taken from the Mississippi State Budget Generator (MSBG) version 6.0. The MSBG used data relevant to the year 2007 and was last updated in January 2007. Data taken from the MSBG included labor, fuel, maintenance, and lubrication costs of a generic sprayer of similar specifications in US dollars per second. The US dollars per second were then converted into US dollars per hectare, consistent with all other costs being analyzed.

Finally, all of the data were then converted into a DBF format which is readable by the program ArcGIS. ArcGIS is an integrated collection of geographic information system (GIS) software products for building a complete GIS. Within ArcGIS, each data point was plotted onto a map. Different layers were generated to represent costs associated with the sprayer and subsequently the development of a map representing the total variable cost as shown in Figure 2.2 through Figure 2.5.

2.4 Results and Discussion

The cost maps indicate that the irregularly shaped field 38 had a relatively evenly distributed cost associated over the aggregate. There were however, some passes in the field where costs jumped dramatically. These jumps in cost are highly correlated with the increased time that was spent between the time the sprayer was turned off and then back on. In making turns, the sprayer was recorded as being turned off for over 3 minutes on some passes. No matter how long the duration, each change in time from the end of one row, to the beginning of the next, was divided by the number of observations from the previous pass and distributed equally to each point's initial change in seconds. This method, which is different from uniform machinery cost allocation, ensures that every second was accounted for in the calculation of variable costs and allocated accordingly. In essence, every second had to be accounted for, so the accumulation of seconds represented in the data at the end of one pass were distributed evenly to every point in that pass. While this approach more effectively represents the data it has the possibility of overestimating the cost for certain rows where the change in seconds was great. By looking at Figure 2.2 through 2.5 it is apparent that the input cost and total variable cost have similar fluctuations in price over the whole field whereas; the repair, fuel, and lubrication costs have similar fluctuations in price for only the points of highest cost. Seeing as how both repair and fuel costs are primarily changed due to the amount of time spent at each given point whereas the input costs are related to time and amount of input applied, the fuel and repair cost maps are similar. High cost values for certain areas could have been influenced by clogs in the sprayer applicators, time efficiency of machines, or by certain path selections.

When looking at the descriptive statistics within Figures 2.2 through 2.5 certain concerns arise. The maximums in the case of fuel, repair and total variable cost show evidence of positive outliers. Further data analysis was done to remove less than 50 of these outliers, which in turn showed no major changes to the cost maps or the information presented. While the removal of the outliers represented a more relevant data set, the calculation of the Total Variable Cost (TVC) mean was found to be somewhat higher than that of other enterprise budgets used for comparison. This somewhat higher mean of the TVC is likely due to the change in performance rate. When looking at the product of speed, width, and efficiency there are expected differences between this study and the studies used for comparison. What was not reflected in the compared data set was the irregular shape of this specific field which alters speed and efficiency.

The difference between the compared enterprise budget and this study, such as a higher TVC mean, highlights a need for farmers to be careful in relying strictly on pre-constructed enterprise budgets. Although they are relatively easy to acquire from different University's and give good guidelines, pre-constructed enterprise budgets are not an accurate representation for the data collected from the Ellis operation.

With the data presented, the Ellis Farm managers might consider upgrading filters on their sprayers and/or changing their path selection for machine operations. The efficiency of the operator is apparent to have cost effects. Utilizing guidance aides such as lightbar decreases the amount of skips and overlaps which in turn decrease the cost associated with each point. Although these are just a few suggestions, with the cost maps as an additional tool, the Ellis Farm will be better able to analyze how much money is being spent spatially on each field.

2.5 <u>Conclusion</u>

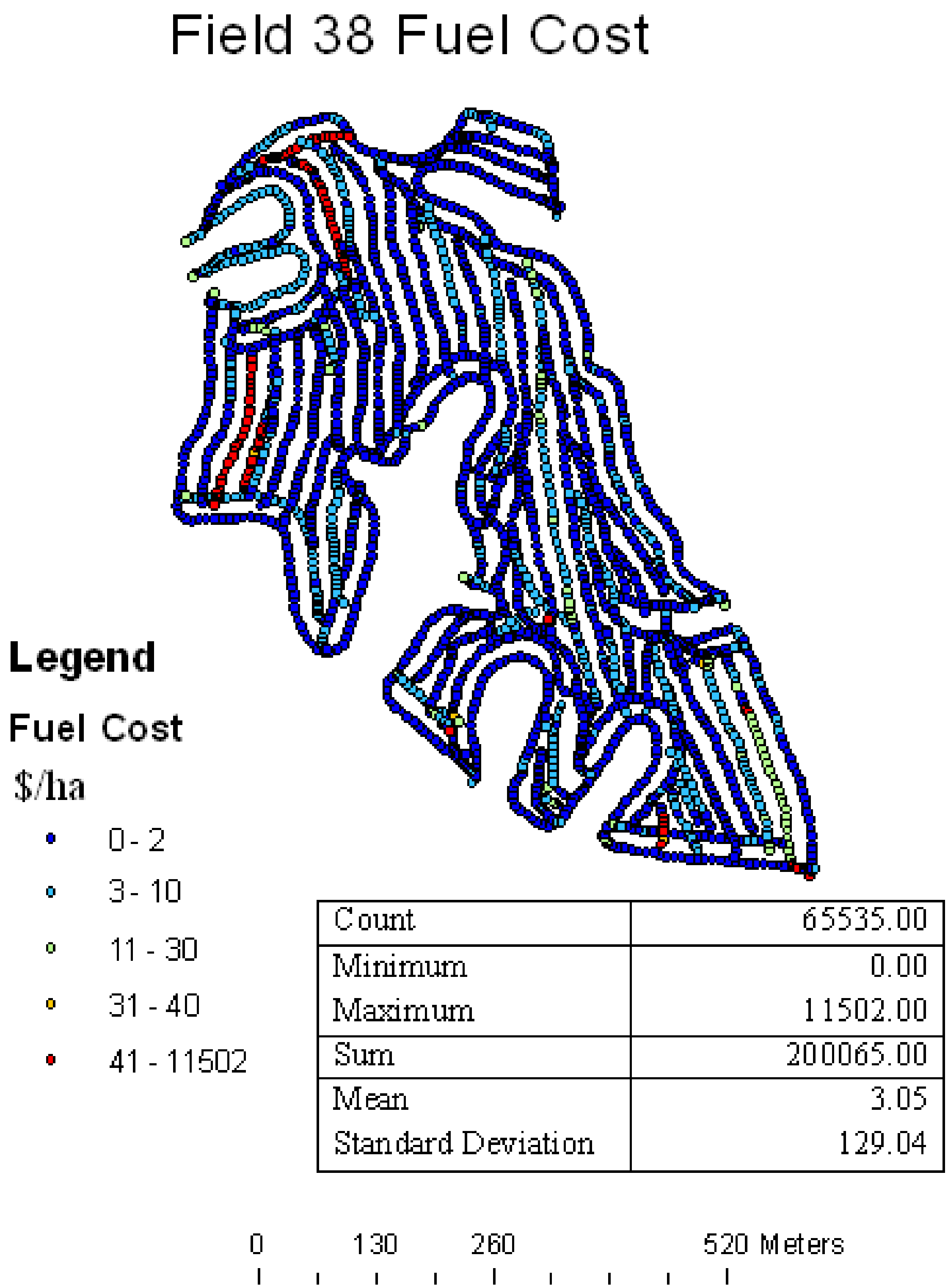
Cost maps have great possibilities in their addition to the set of tools that farmers use in decision making. Even though there are still some adjustments that could be made to increase the accuracy of cost maps, they provide a visual depiction of the variable cost associated with each point of a field for a given machine. The new visual depiction that cost maps offer farmers shows with great detail and simplicity the high cost areas. These visual depictions can aid in management decisions such as changing the machinery optimal path selection or selecting areas of the field that may be removed from production based on the realization of elevated cost in this area. Analysis of the cost maps demonstrates areas of potential production or non production as well as potential for enrollment in the Conservation Reserve Program. One goal of the Conservation Reserve Program is to offset erosion in areas that have high potential for soil loss. This is accomplished by removing these areas from production and offering financial incentive to do so, thus offsetting economic loss in these areas (Stull et al., 2000). These identified areas are referred to as buffer strips. While it may seem desirable to enroll specific costly areas as buffer strips in CRP, there are established criteria and guidelines set forth to be met to qualify for monetary payments.

Analysis of the cost maps also allows for visual identification of problems which could result in higher costs. One example of this could be operator time spent away from the machine i.e. going to use the rest room or to break for lunch, resulting in continually increasing costs. Another example is the realization of the impact of annual calibration or the lack of annual calibration of equipment effecting efficiency, which could be attributed to extra time for field calibrations.

The next step in this study is to generate cost maps for each different machine used on field 38 and compare the statistics. It is possible that with further study it will become evident that certain areas of the field should be removed altogether. Implications may suggest that alternative paths for application have the possibility to decrease the costs.

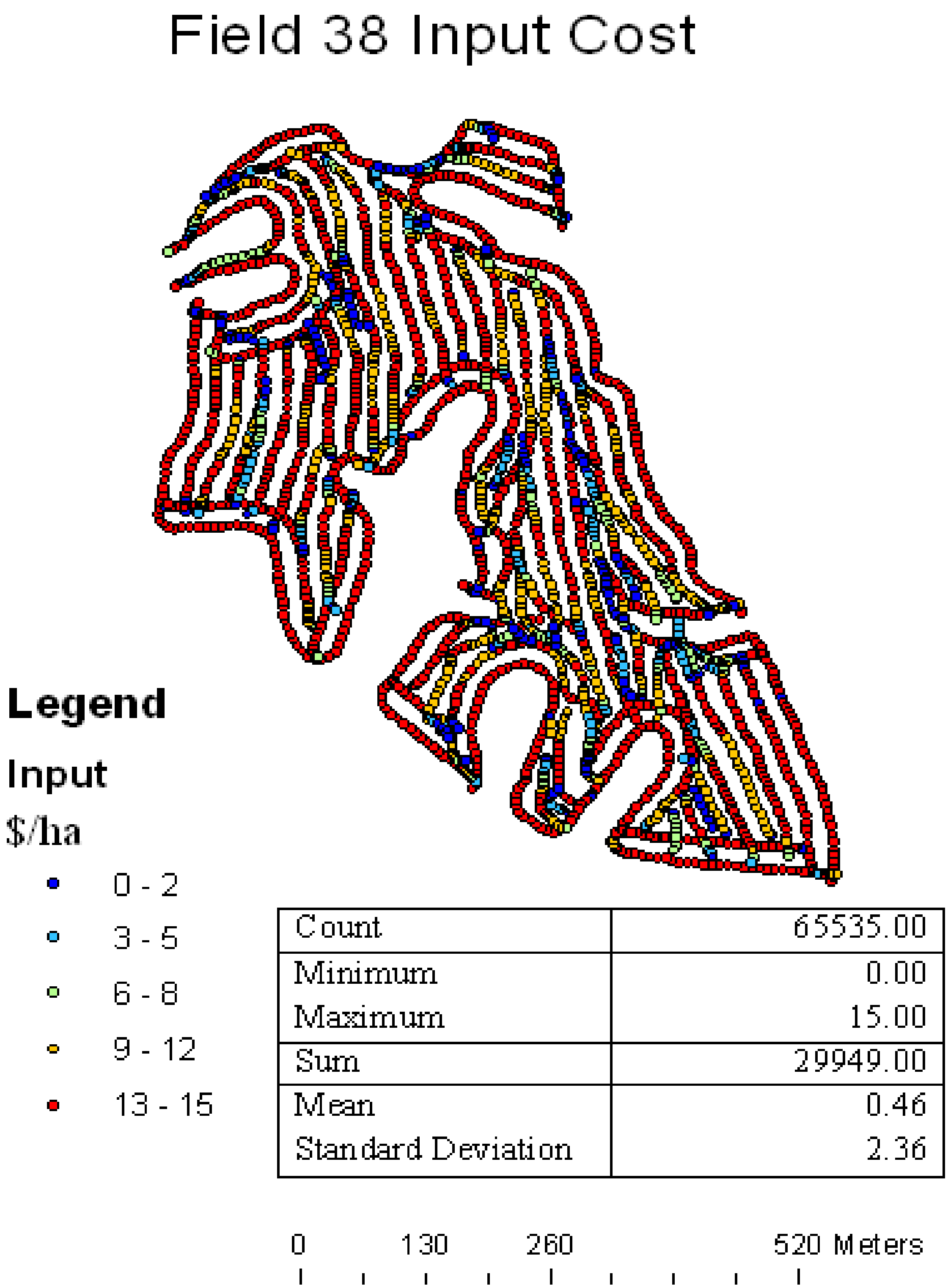
Figure 2.1: RoGator 664 self-propelled sprayer with 24 m boom and map-based single nozzle control system.

Figure 2.2: Field 38 Fuel Cost Produced in ArcGIS



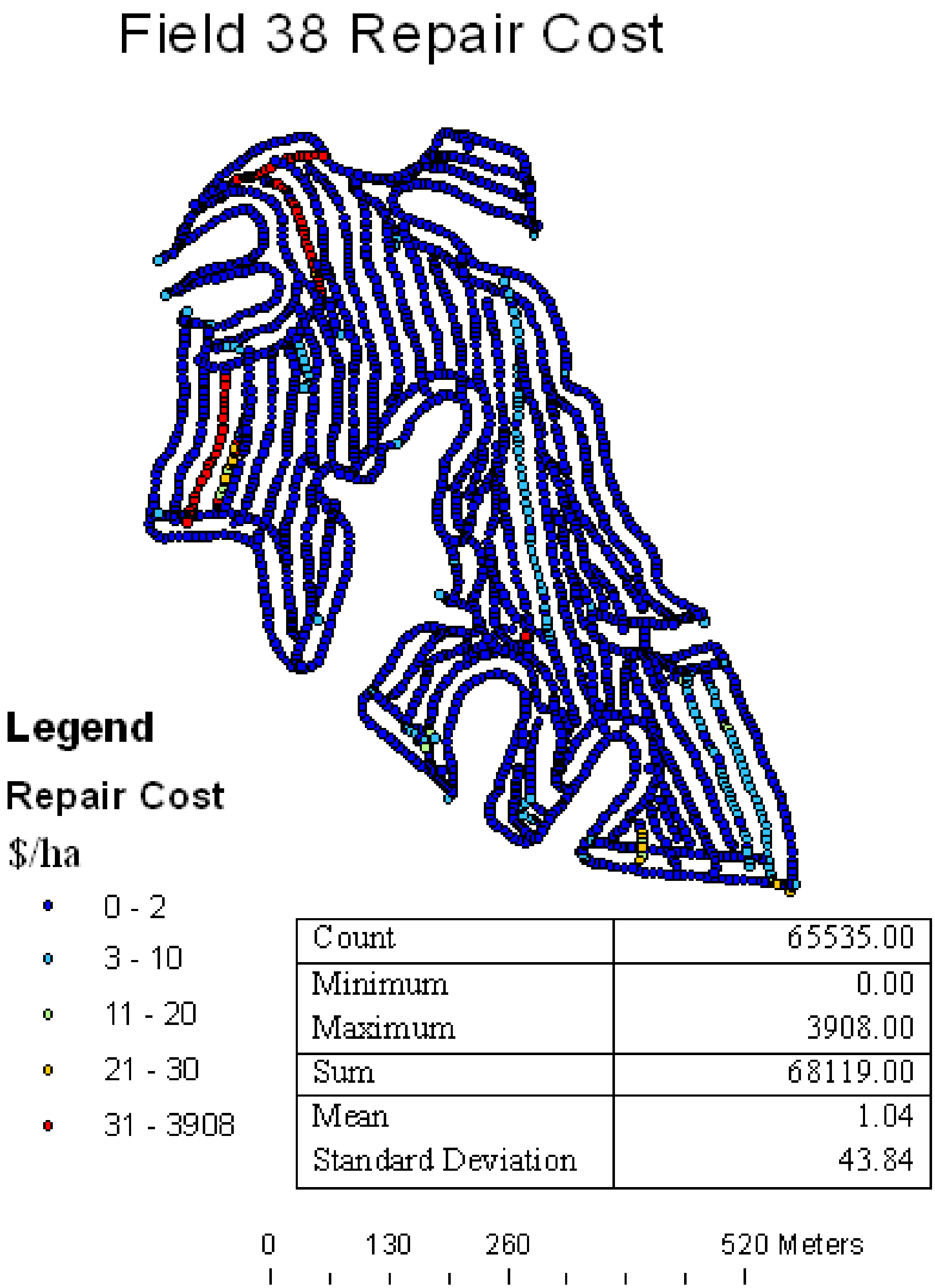
Count	65535.00
Minimum	0.00
Maximum	11502.00
Sum	200065.00
Mean	3.05
Standard Deviation	129.04

Figure 2.3: Field 38 Input Cost Produced in ArcGIS



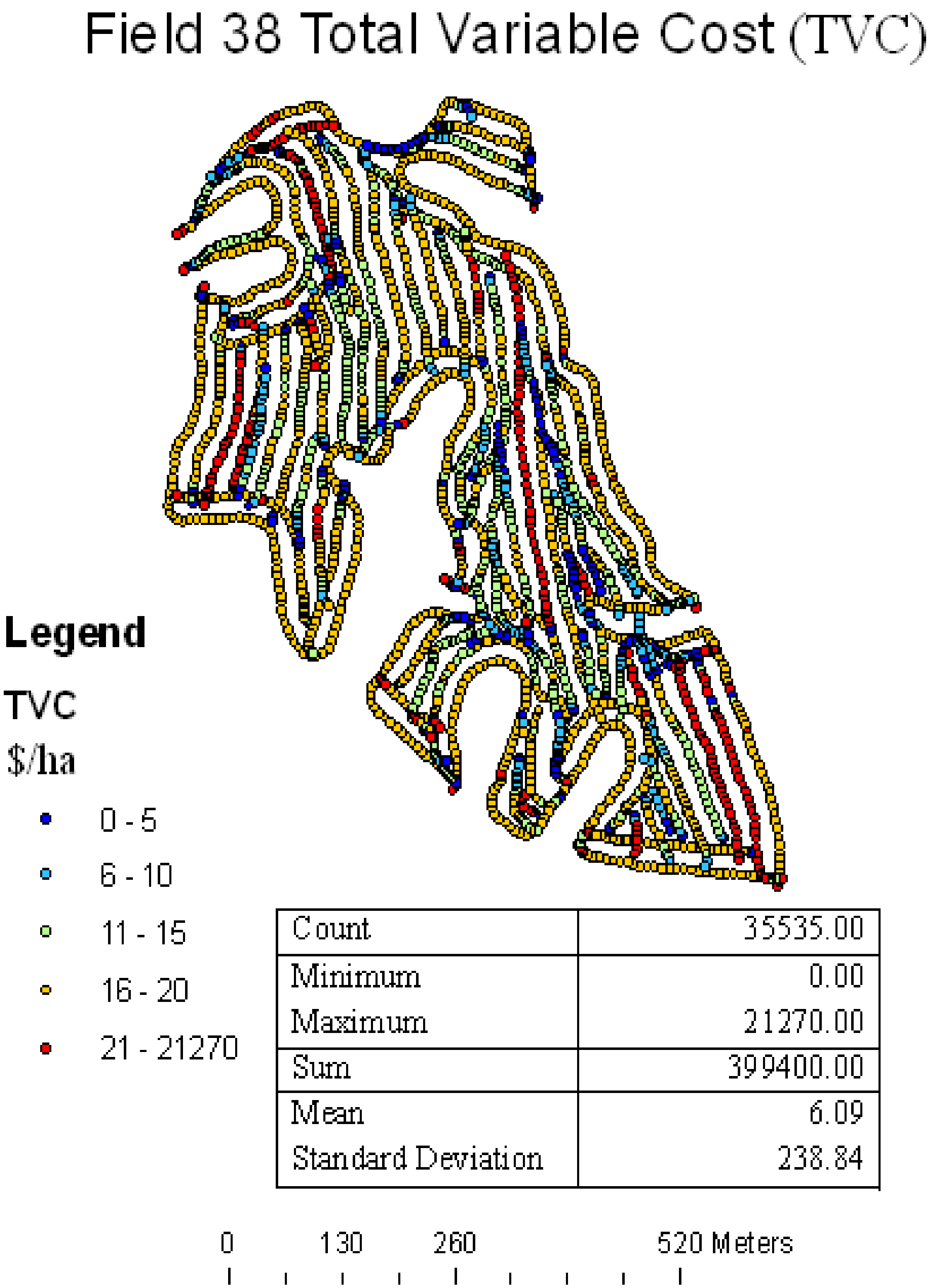
Count	65535.00
Minimum	0.00
Maximum	15.00
Sum	29949.00
Mean	0.46
Standard Deviation	2.36

Figure 2.4: Field 38 Repair Cost Produced in ArcGIS



Count	65535.00
Minimum Maximum	0.00 3908.00
Sum	68119.00
Mean Standard Deviation	1.04 43.84

Figure 2.5: Field 38 Total Variable Cost Produced in ArcGIS



Count	35535.00
Minimum	0.00
Maximum	21270.00
Sum	399400.00
Mean	6.09
Standard Deviation	238.84

Chapter Three

A Whole Farm Modeling Approach to Evaluate the Profitability of Lightbar Technology

3.1 Introduction

Managing a farm is extremely complex and encompasses an environment of multiple risks (Pannel, 1996). The passage of the 1996 Farm Act as well as the 2002 Farm Bill, with less government intervention, heightened the need for risk analysis and risk management. Managing agricultural risk does not necessarily allow for avoidance of risk, but involves the best available combination of risk and return (Hardaker et al., 2004).

The historical farm management based on judgment, guesses, hunches, and outside advice remains valuable but should no longer be the primary focus. The whole-farm model provides a framework for analysis of global aspects impacting the management decisions of economic and yield outcomes. This framework allows the consideration of both economics and technology with a resultant impact on profitability. The whole-farm model incorporates competition across different enterprises for land, labor, and capital.

Today's farm managers need to be able to adapt to changing situations. Farm managers realize that when new technologies emerge into the agriculture community they have a decision of when or if to adopt it. Early adoption has potential for larger gains or losses; whereas later adopters may benefit from the experience of the early adopters, potentially experiencing less risk.

Farmers are continually looking for ways to improve the profitability of their farm. One such way is to avoid lost production associated with unintentionally barren land, while another way is to avoid costly overlaps in input applications. To achieve this goal, farmers have looked towards technology, specifically lightbar technology. Lightbar technology has been around long enough where adoption would not be considered early at this stage. Even though lightbar has proved to be profitable with farmers of the past, there are still farmers that have not realized the potential gains that could be acquired from utilizing this current technology.

The main function of lightbar is to assist the machine operator in driving. Lightbar gives a visual guide that changes colors as the operator veers off the desired path. Previous technologies were developed with the idea of achieving the same goal, for example, planter markers and foam markers. Both of these previous technologies are becoming shadowed by lightbar and its effectiveness in improving farm profitability. As a result, foam and planter markers are becoming an obsolete technology.

Many of the initial studies associated with lightbar have relied upon partial budgeting. Partial budgeting is a great place to start when trying to evaluate the initial economic benefits; however, that is only the first step. Partial budgeting estimates the change in income and expenses as a result of one proposed change in the current farm plan (Kay, Edwards, and Duffy, 2004). This study expands the partial budget framework, which only looks at one instant in time, into a whole farm planning approach which takes into account interactions between different enterprises. This includes competition across enterprises for labor and capital. As an important variable in the farmers' equation, researchers must assess the economic feasibility of a new technology, such as the utilization of lightbar, for the benefit of farmers, and other stakeholders. A whole farm model approach provides for a greater detailed analysis with consideration of the multiple variables which have an impact on the decisions made by farm managers. The whole farm model encompasses interactions between enterprises which is not considered in partial budgets and could result in sub-optimal management decisions. This study will examine the effects of lightbar technology under a whole farm model for a more encompassing view of the overall benefits it provides.

3.2 Literature Review

There are risks in agriculture familiar to any business as well as risks unique to the agricultural industry. Understanding risk is a beneficial starting place to aide farmers in making management choices where adversity and loss are potential outcomes.

Common business risks include human or personnel, financial, institutional and price or market risks. An additional risk unique to agriculture is yield risk. Yield could be impacted by weather as well as application and harvesting errors resulting in reduced yields. Production or yield risks are relatively high in agriculture due to the many uncontrollable natures of agriculture. Variation in temperatures, rainfall, and, insects and diseases are among the most prevalent factors. Technology can play a key role in the yield production risks. Harwood et al., (1999) acknowledge that farmers vary in their attitudes toward risks and risk management. Risk management cannot be a one size fits all approach and requires choosing among alternatives to reduce the effects of the various risk types. “While farmers have different willingness and ability to bear risk, most are willing to sacrifice some level of mean or expected profit to reduce the risk” (Dillon, 2003, p.416). As risk is a factor essential to this study, it was determined that the whole farm model rather than the partial budget model was selected allowing for a more complete analysis.

A partial budget model applies one aspect of change to the estimated changes in income and expenses. Partial budgeting is an economic analytical tool in which one can focus on only changes made to an existing system (Dillon,2003). The limitations of partial budgeting are (1) comparison of the present management plan with one alternative at a time, (2) multiple budgetary applications are required to analyze various alternatives which may be time consuming, (3) interactions across enterprises for labor and capital are not accounted for, and (4) the consideration of risk is not accounted. Partial budgets are incomplete as they fail to consider specific issues, including whole farm interactions and risks. For example, the feasibility of performing all necessary machine operations for the entire acreage being produced under various weather conditions is excluded in an enterprise partial budget analysis. "Thus, it is possible for maximizing the profit for each enterprise will not maximize the profit for the overall farm operation "(Dillon, 2003, p.414).

The whole farm model is an outline or summary of the type and volume of production for an entire farm. This application can be designed for a specific time frame with the consideration of changes and their impact on the entire operation. Risk exposure can be identified with this model with the application of (1) goal setting, (2) physical, financial and human resource assessment (3) enterprise and technical coefficient analysis (4) identification of a recommended plan and (5) identification of budgetary expenditure (Kay et al., 2004).

Precision farming may seem to be a relatively new term, but the concept is well-established. Precision farming can be defined as "a philosophy of farm operation and management that used both agronomic data and modern technology to maximize the efficiency of the agricultural production system" (Ima and Mann, p.2). Higher yields, reduced inputs and lower risk have been the primary objectives of farmers employing these technologies. Because of further advancing technology, farmers now have the ability to use components of guidance systems such as computers, global positioning systems (GPS), and lightbars in their farming operations.

There are two classifications of guidance systems for agricultural production: autonomous systems, and guidance aides. The intent of the autonomous system is to free up the operator of the machine from the guidance task and thus improve operating efficiency. Guidance aides are devices that provide guidance information to the operator and still require the operator to fully control the machines operations. Kaber and Endsley (1997) contend that critical issues exist with autonomous systems with "out of the loop" performance or the lack of an operator. Concerns with autonomous systems are related to the loss of situational awareness and operator failure in regards to assessing situations and making needed changes, over the trust placed in computers may lead to negative impacts. Guidance aide systems in which the level of automation is blended with human operator and computer control are advantageous and may lead to cost reductions.

The term guidance aide refers to "devices that provide guidance information to the operator but do not attempt to replace the operator" (Ima and Mann, p.2). Historically farmers have turned to the use of guidance aides to assist in maximizing production; using simple guidance aides such as flags, stakes, fence posts, and foam markers to reduce guidance error. One of the most broadly adopted and more recently developed methods to reduce guidance error is the lightbar technology.

The main function of lightbar is to assist the machine operator in driving; thus decreasing operator fatigue and minimizing application errors of overlaps and skips. The term ‘lightbar’ refers to a monitor which is a plastic case with a row of light emitting diodes (LEDs) inside it (Figure 3.1). “Most lightbar systems include a Differential GPS (DGPS) receiver and antenna, some kind of computer or microprocessor, and a lightbar or graphics display” (Stombaugh, p.1, 2002). The LEDs are positioned to the right and left of a center position. When driving corrections need to be made, the LEDs will flash or illuminate on the side in which the driver needs to turn. In this way, the driver has a constant visual representation of where they need to be in order to reduce overlaps and misses. A visual depiction of a lightbar is shown in Figure 3.1.

Lightbar is one of the most recent technologies that is replacing foam markers. Foam markers are used by farmers by dropping a foam blob from the end of an applicator boom, or sometimes the center of the applicator when booms are not utilized. After the foam blob is deposited on the field, the operator uses it as a visual indicator to know where the applicator has passed (Grisso and Alley, 2002). There are several reasons why lightbar is replacing foam markers:

> “lightbar is more reliable and more accurate than foam markers, lightbar allows accuracy at higher speeds, lightbar is a possibility with spinner spreaders, lightbar is easy to use, lightbar provides effective guidance over growing crops, lightbar allows operation when visibility is poor, lightbar is less affected by weather, and lightbar has lower recurring costs” (Buick and White, 1999, p.425).

Based on identified advantages of lightbar technology over other technologies, studies have been done to see what effect it has on farms’ profitability as determined with partial budgeting. A study from Purdue University addressed the economic feasibility of lightbar, as well as other technologies, using a partial budget in a linear programming model (Griffin, Lambert, and Lowenberg-DeBoer, 2005). Griffin indicates that lightbar is commercially available and promises increased efficiency of field operations. Five scenarios were compared in the study: (i) a baseline scenario with foam, disk or other visual marker reference, (ii) lightbar navigation with basic GPS availability (+/-3 dm accuracy), (iii) lightbar with satellite subscription correction GPS (+/-1 dm), (iv) auto-guidance with satellite subscription (+/-1 dm), and (v) auto-guidance with a base station real time kinematic (RTK) GPS (+/-1 cm). The returns from each scenario were then compared over incremental management scenarios (Griffin, Lambert, Lowenberg-DeBoer, 2005.). Initial results showed that adding lightbar with 3 dm accuracy increased the contribution margin by US$4,895 or US$4.03 ha^{-1}. Next a partial budget was created from the linear programming (LP) results. Assumptions were made about useful life, discount rate, and salvage value, with each assumption holding great implications on the calculated results. The results showed that lightbar was profitable when no land was added as well as when land was added. The adoption of lightbar depended on cost and availability of capital and labor, as well as potential for farm expansion; consequently, the results may vary depending on location of the study.

The study conducted by Griffin, Lambert, and Lowenberg-DeBoer was an excellent starting point that encompassed many different variables. Where their research is lacking though is the analysis of lightbar in a whole farm model. Although considerably more time consuming, the idea of interactions between different enterprises and the competition across those enterprises for labor and capital are realized and accounted for in a whole farm model. This study improves on past studies by incorporating multiple enterprises, risk, and the idea of competition for labor and capital between those enterprises.

3.3 <u>Data and Methods</u>

The whole farm model for evaluating the profitability of lightbar technology is essentially a resource allocation model. This classic linear programming involves the allocation of an endowment of scarce resources among a number of competing products so as to maximize profits (McCarl). The model depicts a hypothetical Kentucky crop producer on a loamy soil in Henderson County, located in the Ohio Valley region of Kentucky (Dillon, 1999).

The expected value-variance (E-V) model, originally motivated by Markowitz, states that decisions are made using the mean and variance of net returns, preferring a higher mean and lower variance. This realization came after Markowitz observed that investors only placed a portion of their funds in the highest-yielding investments. After noticing this, Markowitz argued that "an LP formulation is inappropriate since an LP would reflect investment of all funds in the highest yielding alternative" (McCarl, p.373). To incorporate lightbar the specific E-V model is modified from Dillon's (1999, p.251-2) model and shown below:

$$\text{Max} \quad \bar{y} - \phi\sigma_y^2$$

s.t. (1) $$\sum_E \sum_V \sum_P \sum_S X_{E,V,P,S} \leq 1350$$

(2) $$\sum_E \sum_V \sum_P \sum_S LABLB * LAB_{E,S,WK} X_{E,V,P,S} \leq FLDDAYLB * FLDDAY_{WK} \quad \forall WK$$

(3) $$\sum_E \sum_V \sum_P \sum_S EXPYLDLB * EXPYLD_{C,E,V,P,S,YR} X_{E,V,P,S} - SALES_{C,YR} = 0 \quad \forall C, YR$$

(4) $$\sum_{E}\sum_{V}\sum_{P}\sum_{S} REQLB * REQ_{I,P*}X_{E,V,P,S} - PURCH_{I} = 0 \qquad \forall I$$

(5) $$\sum_{I} IP_{I} PURCH_{I} - \sum_{C} P_{C} * SALES_{C,YR} + LBCOST + Y_{YR} = 0 \qquad \forall YR$$

(6) $$\sum_{YR} \frac{1}{N} Y_{YR} - \overline{Y} = 0$$

(7) $$\sum_{E}\sum_{V}\sum_{P}\sum_{S} ROTATE_{R,E} X_{E,V,P,S} \leq 675 \qquad \forall R$$

where activities include:

$\overline{Y}$ = expected net returns above variable cost (mean across years)
Y_{YR} = net returns above variable cost by year (net returns)
$X_{E,V,P,S}$ = production of enterprise E of variety V with a plant population P under sowing date S in acres
$SALES_{C,YR}$ = bushels of crop C, sold by year
$PURCH_{I}$ = purchases of input I

constraints include:

(1) Land resource limitation
(2) Labor resource limitations by week
(3) Sales balance by crop and year
(4) Input purchases by input
(5) Profit balance by year
(6) Expected profit balance
(7) Rotation limitations

coefficients include:

ϕ = Pratt risk-aversion coefficient
P_{C} = Price of crop C in dollars per bushel
IP_{I} = Price of input I
$EXPYLDLB$ = Multiplier representing area planted without lightbar = 1 and with lightbar = 1.02 as discussed below
$EXPYLD_{C,E,V,P,S,YR}$ = Expected yield of crop C for enterprise E of variety V planted in population P planted on sowing date S in bushels per acre for

year YR

$REQLB =$ Multiplier representing requirement of input under production without lightbar = 1 and with lightbar = .98 as discussed below

$REQ_{I,P}$ = Requirement of input I for production in row and plant spacing P in units per acre

$LABLB =$ Multiplier representing labor requirements under production without lightbar = 1 and with lightbar = $\frac{.85}{.9}$ as discussed below

$LAB_{E,S,WK}$ = Labor requirements for production of enterprise E planted on sowing date S in week WK in hours per acre

$FLDDAYLB =$ Multiplier adjusting available field days to reflect a 13 hour day with lightbar and a 12 hour day without as discussed below

$FLDDAY_{WK}$ = Available field days per week

$ROTATE_{R,E}$ = Rotation categorization matrix by enterprise E to include corn if R= 1 and other crops if R = 2

indices include:

C = Crop
E = Enterprise
V = Variety (MG III, IV, and V for soybeans or Early, Medium, and Late for corn)
P = Plant population
S = Sowing date
I = Input
WK = Week
YR = Year
R = Rotation category

The E-V model is maximizing the expected net returns above variable cost. In doing so it has to choose a maximum solution that does not exceed: (1) the amount of land available at 1350 acres, (2) or the two year rotation requirement which represents half the acres, to ensure for instance corn is not planted consecutively for two years. The amount of labor required for production must not exceed the amount of available field days. The amount of crop sold is equal to the amount of production. Input purchases calculated are based on the sum of input requirement and total acreage produced. The sales and input purchases are used in calculating net returns by year, which in turn are averaged to estimate mean net returns. Yields for each enterprise are represented in the model from past data collected. Each enterprise has its own related production input requirement which represents the variable costs associated with each crop. Labor requirements, which differ by enterprise, are accounted for by tables in the model. The farm size, which stayed constant given lightbar, or no lightbar, was allotted at 1,350 tillable acres. This number was derived by rounding the average number of tillable acres for an Ohio Valley grain farm of 1,346 up to 1,350 (Dillon, 1999 and Morgan, 1998). Available field time is calculated by multiplying the average number of workable field days a week by 13 working hours a day (number determined for lightbar) for 2.56 persons, the average number of persons working on Ohio Valley farms (Dillon, 1999 and Morgan, 1998).

The data used from Dillon and Morgan needed expansion to include all years up to 2006. The expansion took place by collecting weather data for those years between 1998 and 2006 from the Kentucky State weather data service and entering it into the existing model.

This specific model's objective function value represents the average profits expected by the farmer. To obtain this value, the cost of the lightbar instrument was subtracted from the average profits. The constraints consisted of land, labor, and capital. Because of the size and complexity, the program General Algebraic Modeling System (GAMS) was used in solving the model. There are other options that solve linear programming models such as Microsoft Excel, but the capability of GAMS is more suited for large complex problems such as whole farm modeling whereas Excel might be more suited for partial budgeting.

Lightbar is similar to many new technologies in that it helps with the achievement of goals in a more efficient manner. The use of a lightbar reduces skips and overlaps in machinery operations. “Most operators, in typical field operations, tend to overlap subsequent passes to avoid the more noticeable effects of a skip.” (Stombaugh, 2002, p.2) Consequently, labor costs as well as production input requirements were hypothesized to decrease with the implementation of lightbar, whereas the yields of each enterprise and time availability were hypothesized to increase as a result of lightbar. Reduced skips and overlaps allow an operator to cover more land area for a given amount of time, essentially requiring fewer passes to cover the field which in turn increases performance rate causing labor costs to decrease. Labor requirements were therefore decreased by a factor of (0.85/0.9) (Griffin, 2007). A direct assessment of possible input savings (i.e. chemical) was expanded into an input requirement reduction by 2% realizing that the same amount of input is covering more area (Stombaugh et al., 2003). A yield increase was derived by evaluating the reduced skips and overlaps, coming up with the most reasonable number of an increase of 2%. Sensitivity analysis was also done where the yield benefit was zero. Because of lightbar and its ability to assist the operator in more accurately maneuvering the machine during fertilization (i.e. reducing skips as well as enterprise collection), the crop yield increases. This benefit is represented by the 2% increased yields attributed to the model when lightbar is evaluated in the equation. Time availability was increased from 12 to 13 hours to include the extended day afforded by lightbar (Griffin, Lambert, Lowenberg-DeBoer, 2005). The cost of lightbar, which varies between $2,000 and $5,000 (Stombaugh et al., 2003) was estimated to have an annual cost of $980. The annualized cost of lightbar was calculated as the sum of depreciation and interest expense. These costs were derived using a straight-line depreciation with a five year useful life, zero salvage value, risk neutral producer, and assuming an interest rate of eight percent.

The initial model was run without lightbar as a reference for the lightbar model. The initial model had a net farm income above selected costs (NFI) of $176,365. When lightbar was added to the model the NFI increased by $10,768 or 6.11% giving a new NFI of $187,134. This value represents the initial cost of lightbar and all of the expected benefits that will occur from the use of it. Realizing that not every farmer is equal, sensitivity analyses as well as multiple iterations dealing with different varying levels of risk were conducted to study the effects of changes to the model.

In each run of the model there were nine levels of risk observed. The first level looked at a risk neutral individual and the next eight looked at further varying levels of risk aversion. The Pratt risk-aversion function coefficient is a measure of a producer's aversion to risk (Dillon, 1999). This coefficient is calculated in the research previously done by Carl Dillon (Dillon, 1999), wherein a producer is said to maximize the lower limit from a confidence interval of normally distributed net returns. The resulting risk aversion coefficient embodies the producer's attitude towards risk, represented by the variance of net returns. The formula for calculating the risk aversion parameter is:

$$\phi = \frac{2Z_{\alpha}}{S_y}$$

where $\phi =$ risk-aversion coefficient, $Z_{\alpha} =$ the standard normal Z value of α level of significance, and $S_y =$ the relevant standard deviation the risk-neutral profit maximizing base case for each (McCarl and Bessler, 1989). Although there were nine different levels of risk aversion observed, only the first three were deemed relevant due to the fact that in the last six levels the hypothetical farmer produced wheat as a single crop, which is not a common practice for Ohio Valley farms. In the interest of space, the multiple levels of risk aversion observed were then grouped into four levels of risk aversion: starting with risk neutral, then low risk aversion ($\alpha = 50\%$), medium risk aversion ($\alpha = 55\%$), and finally high risk aversion ($\alpha = 60\%$). A tool used to analyze risk aversion is application of the coefficient of variation (CV).

The CV which is the ratio of the standard deviation to the mean, continually decreases as risk aversion goes up. A risk averse producer may prefer a cropping system with a lower mean expected net return but a lower CV of expected net returns over a cropping system with a greater expected net returns but a higher level of CV (Dillon, 2003). Results of this study will include the CV analysis and implications.

3.4 <u>Results</u>

With four different categories of risk incorporated including risk neutrality, the economic and production differences between the hypothetical Ohio Valley farm with lightbar and without lightbar were substantial. As discussed above, results from the original experiments of the farm with and without lightbar were grouped into four different levels: risk neutral, low risk aversion, medium risk aversion, and high risk aversion. These results in their respective levels are shown in Table 3.1 through 3.3.

It was hypothesized that in the case of risk neutrality the expected net returns are higher with lightbar. It was also hypothesized that C.V. would decrease when lightbar was added as well as in higher levels of risk aversion. When looking at higher levels of risk aversion with lightbar, the C.V. is consistently lower than the without lightbar C.V. representing a greater opportunity to manage risk.

The sensitivity analysis depicted in Table 3.2 reflects the specific attributes of lightbar with respect to time requirements, labor costs requirements, input costs requirements and yield benefits. With each attribute adding a positive influence to the expected net returns of the lightbar case, some represent a greater percent of the optimal example which takes into consideration all attributes. When all of the attributes are considered, adopting lightbar not only reduces risks but increases expected net returns.

The obvious difference between the farm with lightbar and without lightbar is the change in net returns above variable cost. The net returns above variable cost improved by $10,768.99, representing a 6.11% increase. What is not as obvious is the changes in the production practices. Without lightbar availability optimal double cropped soybean production was limited in resource allocation when deciding how much to devote to each sowing date, whereas when lightbar and all its attributes were added to the model, adjustments were made to allocate different quantities to the more beneficial sowing dates. This fact was hypothesized initially with the thought that added time availability during the critical time of planting would increase critical sowing dates in double crop production. The adjustment towards the more beneficial sowing dates in soybean production can be attributed to the fact that there are more suitable field days available with lightbar mainly because of the extended amount of workable day that is provided by lightbar (Griffin, Lambert, Lowenberg-DeBoer, 2005).

Sensitivity analysis is a procedure for assessing the riskiness of a decision by using several possible price and or production outcomes to budget the results, and then analyzing and comparing the results (Kay et al., 2004). The question arises as to the relative contributions of the various benefits of lightbar (i.e. yield, suitable field days, input requirements and labor requirements) on economic and production decision results. Thus the desire to evaluate each benefit individually comes forth, requiring sensitivity analysis. Sensitivity analysis was performed on the data in order to look at the relative impacts each individual benefit contributed to the overall benefit of lightbar. These results can be observed in Tables 3.4 though 3.7.

In the original case the model focused on the differences between a farm which adopts lightbar and one that does not. The economic results, shown on Table 3.1, exemplify the benefits that lightbar contributes to the farm. The farm with lightbar has a higher expected net return and maximum net return while showing a positive minimum net return as opposed to the negative amount represented by the farm without lightbar. As the risk aversion increases expected net return decrease for both cases but the farm that adopted lightbar continually has a higher expected net return. In the risk neutral case the CV is shown to decrease when lightbar is added, implying a greater potential to manage risk. Then when evaluated at the high risk aversion the CV is still less than that of the without lightbar case but not at such a difference. Where at the risk neutral case the CV difference is 5.13% and at the high risk aversion level the CV difference is 4.85%. This implies that even though the ability to manage risk is still greater at all varying levels of risk for the case of lightbar, there is a greater potential for risk reduction at lower levels of risk aversion.

The production results for the original case, shown on Table 3.3, illustrate that the farm which has adopted lightbar moves resources from sowing dates that are later in the year to those that are earlier for both double crop soybeans and wheat as well as corn. This change in choosing more enterprises to be planted earlier in the year exemplifies the benefit of longer field days.

The first sensitivity analysis to be preformed examined the lightbar case without the extra hour per day afforded by lightbar. The time available without lightbar was calculated to be 12 working hours a day whereas with lightbar the hours were increased to 13 working hours a day (Griffin, 2007). In the sensitivity analysis holding everything else constant the lightbar model was forced to run under the constraint that there could only be 12 working hours a day. This in essence allowed lightbar to be evaluated without its time benefit. When looking at the economic results there was a reduction in expected net returns, implying that the increased time availability that lightbar affords increases expected net returns. CV increased in the risk neutral case and then changed only slightly in the higher risk aversion cases. The most notable change in the production results is the shift in double crop soybeans and wheat from the earlier sowing date of September 27th to the later date of October 4th. This change indicates that a key factor in the planting date of September 27th for double crop soybeans and wheat is the time allotted for each day's workable hours.

The next sensitivity analysis examined was the reduced time requirement. Due to the consideration that laborers are able to cover more ground per hour with lightbar, there are different costs associated with labor in respect with lightbar. This part of the sensitivity analysis evaluated the lightbar model holding all else constant while constricting the labor requirements to the without lightbar model level. The economic results showed the change in the expected net returns to have a 0.16% decrease when the labor cost requirements were held to the numbers of the without lightbar example. This brings to light the idea that the labor cost savings which lightbar bring to the farm are not the major contributing factors that change expected net returns. Although, the labor cost requirements did not contribute much to the expected net returns they were the only other factor that caused the double crop soybeans and wheat to be planted at the later date of October 4th instead of September 27th.

The next sensitivity analysis looked at the reduced input costs. Input cost requirements are calculated to decrease by two percent due to the reduction of over application. This 2% reduction is reflected in the economic results as a 2.7% change in the expected net returns. Without the reduction in input cost the CV increased slightly implying that when lightbar is able to reduce the input costs it is also able to decrease risk. Looking at the combination of the input cost reduction along with the yield benefit explain for the majority of the change in expected net returns.

The final sensitivity analysis evaluated looked at lightbar without the yield benefits. This evaluation was found to be the most interesting mainly because the results were not expected to be very important. Yield benefits which are calculated to increase by 2% have a 3.22% positive impact on net returns. The statistical analysis study shows that yield benefits, along with reduction in input costs are the only factors that when changed to the without lightbar numbers cause the minimum net returns to be negative. This means that in order for the model to have a positive minimum net returns both the reduction in input costs and increased yield benefits need to be accounted for. This also brings forth that biggest gains from the addition of lightbar, with respect to net returns, comes from the yield benefits associated with lightbar.

3.5 <u>Conclusions</u>

This model has shown that lightbar has the potential to not only increase profits but reduce risks associated with those profits. With the near 6.11% increase in net returns above variable cost and a decrease in CV, lightbar shows significant promise to the farmers of the Ohio Valley region. When it is shown that lightbar increases expected net returns as well as reduces risk there are questions as to why every farmer does not have a lightbar system on their farm. This can only be answered on a farm by farm basis. In some cases farmers have been given the stereotype of being reluctant to change. If the information from this study was brought to a farmer who has made a living of farming his whole life and might be nearing retirement, that farmer is less likely to be enthused about changing his farming practices that have worked for years to something new that deals with technology.

A break even analysis was preformed to find the acreage needed to make lightbar profitable. The break even acreage was found to be 44.5 acres. That means that if you have 44.5 acres you are indifferent in adopting lightbar or not, where those farmers below 44.5 acres do not adopt and those above do adopt. Another reason that lightbar may not be adopted is that not all farmers own their own equipment and therefore do not have the rights to make changes to that equipment.

Assumptions in the model are made that there are typical overlaps and misses in input applications, which commonly occur without lightbar. Further assumptions are that lightbar reduces operator fatigue and increases the ease of working early in the morning and late in the evening. Without these assumptions the model and its dynamics would change. This model shows how a hypothetical Ohio Valley region farm would react to the introduction of lightbar. The final values and differences between the farm with and without lightbar differ from other studies because this model represents a whole farm with the ability to incorporate competition across enterprises for labor and capital.

Overall, lightbar enables operators to have longer field days, more efficient field practices such as reduction of overlap and skips, and experience less fatigue. Although the implications of this study show a positive relation between lightbar adoption and profit, this value is dependent on the cost and availability of capital and labor. The model focuses on capital intensive economies such as the United States where labor is more readily substituted for capital, whereas studies of the same type in other regions might have different results. Because of its low annualized cost, learning curve and potential for increased net returns above variable cost, lightbar is an easy first step into using precision agriculture.

As more farmers in the Ohio Valley region adopt lightbar it will become easier to evaluate its effects on farm profitability and risk reduction due to the comprehensive records that are being kept by farmers in that area. With multiple years of lightbar data and today's farmer becoming more proficient at data collection and storage, researchers will be able to perform farm specific analysis giving farmers more tailored information.

Figure 3.1: Model representing the type of lightbar available through Trimble. Model consists of a row of LEDs, with three green, and fourteen red on either side of the central green LED, as well as a screen below (Trimble).

Table 3.1: Economic Results of a Hypothetical Ohio Valley Farm With and Without Lightbar

Risk Neutral	**Without LB**	**Lightbar**
Expected N/R	$176,365.04	$187,134.03
C.V.	55.71	52.85
Min N/R	-$4,857.36	$4,922.14
Max N/R	$333,089.42	$345,542.69
Low Risk Aversion		
Expected N/R	$151,720.20	$162,368.08
C.V.	55.38	52.51
Min N/R	-$4,948.57	$4,902.16
Max N/R	$330,002.50	$342,846.33
Medium Risk Aversion		
Expected N/R	$128,035.60	$138,207.36
C.V.	53.9	51.50
Min N/R	-$10,216.52	$2,257.16
Max N/R	$323,767.19	$338,791.91
High Risk Aversion		
Expected N/R	$106,441.63	$116,103.38
C.V.	50.88	48.41
Min N/R	-$6,112.23	$3,111.43
Max N/R	$287,690.72	$302,311.84

Table 3.2: Economic Results of a Hypothetical Ohio Valley Farm With Lightbar Sensitivity Analysis

	All Lightbar	Lightbar Benefits Without			
Risk Neutral	**Benefits**	Time Req	Labor Cost Req	Input Cost Req	Yield Benefits
Expected N/R	$187,134.03	$186,719.87	$186,834.92	$182,085.71	$181,102.99
% of Optimal	N/A	99.78%	99.84%	97.30%	96.78%
C.V.	52.85	52.9	52.88	54.31	54.36
Min N/R	$4,922.14	$4,466.14	$4,592.81	-$126.19	-$43.94
Max N/R	$345,542.69	$344,750.59	$344,970.62	$340,494.36	$338,443.92
Low Risk Aversion					
Expected N/R	$162,368.08	$162,006.45	$162,107.10	$157,319.76	$156,564.96
% of Optimal	N/A	99.78%	99.84%	96.89%	96.43%
C.V.	52.51	52.58	52.56	53.97	54.01
Min N/R	$4,902.16	$4,422.37	$4,555.64	-$146.16	-$117.13
Max N/R	$342,846.33	$341,853.92	$342,129.59	$337,798.01	$335,747.44
Medium Risk Aversion					
Expected N/R	$138,207.36	$138,007.20	$138,075.44	$133,159.04	$132,700.47
% of Optimal	N/A	99.86%	99.90%	96.35%	96.02%
C.V.	51.50	51.37	51.44	53.1	53.04
Min N/R	$2,257.16	$19.23	$570.65	-$2,791.17	-$3,372.10
Max N/R	$338,791.91	$336,416.58	$337,117.53	$333,743.59	$331,328.72
High Risk Aversion					
Expected N/R	$116,103.38	$116,058.97	$116,072.12	$111,161.00	$110,842.76
% of Optimal	N/A	99.96%	99.97%	95.74%	95.47%
C.V.	48.41	48.4	48.4	49.76	49.95
Min N/R	$3,111.43	$2,304.31	$2,528.57	-$1,415.45	-$2,417.10
Max N/R	$302,311.84	$301,821.12	$301,957.43	$295,987.05	$296,366.20

Table 3.3. Production Results of a Hypothetical Ohio Valley Farm With and Without Lightbar Adoption for Different Levels of Risk

		Risk Neutral		Low Risk Aversion		Medium Risk Aversion		High Risk Aversion	
		With Lightbar	Without Lightbar	With Lightbar	Without Lightbar	With Lightbar	Without Lightbar	With Lightbar	Without Lightbar
Double Crop Soybeans	S27. MG3	29.43	92.51	385.41	336	347.45	315.62	325.5	270.8
	S27. MG4	216.41	104.77	150.18	83.62	211.81	196.37	50.95	78.99
	S27. MG5	341.45	314.72	51.71	92.38	1.04			
	O04.MG4			30.07	154.74				
	O04.MG5	87.71	163	57.63	8.26				
	N22.MG5					87.71	163	195.25	212.97
Wheat								103.29	112.24
Corn	A26. late			7.48	34.84	66.03	168.52		
	Ao5. late	474.35	413.54	474.35	413.54	474.35	413.54	370.56	413.54
	A19. late	200.65	261.46	193.17	226.62	120.05	92.94	304.44	220.56
	M24. late					14.57			40.9
Soybean Yield	Bu/ac	28.71	28.79	28.67	28.75	29.17	29.69	30.15	30.33
Wheat Yield	Bu/ac	58.67	57.07	58.67	57.07	56.6	53.3	53.41	51.85
Corn Yield	Bu/ac	125.52	122.99	125.52	122.99	125.52	123	125.4	122.97

Where A26 = sowing data of April 26th, S27 = sowing date of September 27th, A05 = sowing date of April 5th, A19 = sowing date of April 19th, mg4 = plant variety 4 for soybeans, mg3 = plant variety 3 for soybeans, mg5 = plant variety 5 for soybeans, .late = plant variety late for corn.

Table 3.4: Production Results of a Hypothetical Ohio Valley Farm for Lightbar Adoption Sensitivity Analysis Under Risk Neutrality

			Risk Neutral Lightbar w/o			
		All Lightbar Benefits	Time Req	Labor Cost Req	Input Cost Req	Yield Benefits
Double Crop Soybeans	S27. MG3	29.43	67.28	56.77	29.43	29.43
	S27. MG4	216.41	149.43	168.03	216.41	216.41
	S27. MG5	341.45	325.41	329.87	341.45	341.45
	O04.MG4					
	O04.MG5	87.71	132.88	120.33	87.71	87.71
	N22.MG5					
Wheat						
Corn	A26. late					
	Ao5. late	474.35	437.86	448	474.35	474.35
	A19. late	200.65	237.14	227	200.65	200.65
	M24. late					
Soybean Yield	Bu/ac	28.71	28.76	28.74	28.71	28.71
Wheat Yield	Bu/ac	58.67	58.4	58.47	58.67	57.52
Corn Yield	Bu/ac	125.52	125.48	125.49	125.52	123.06

Where A26 = sowing data of April 26th, S27 = sowing date of September 27th, A05 = sowing date of April 5th, A19 = sowing date of April 19th, mg4 = plant variety 4 for soybeans, mg3 = plant variety 3 for soybeans, mg5 = plant variety 5 for soybeans, .late = plant variety late for corn.

Table 3.5: Production Results of a Hypothetical Ohio Valley Farm for Lightbar Adoption Sensitivity Analysis Under Low Risk Aversion

			Low Risk Aversion Lightbar w/o			
		All Lightbar Benefits	Time Req	Labor Cost Req	Input Cost Req	Yield Benefits
Double Crop Soybeans	S27. MG3	385.41	355.76	364	385.41	385.41
	S27. MG4	150.18	104.15	116.93	150.18	166.81
	S27. MG5	51.71	82.21	73.73	51.71	35.07
	O04.MG4	30.07	103.98	83.45	30.07	21.86
	O04.MG5	57.63	28.91	36.88	57.63	65.84
	N22.MG5					
Wheat						
Corn	A26. late	7.48	16.39	13.92	7.48	27.96
	Ao5. late	474.35	437.86	448	474.35	474.35
	A19. late	193.17	220.74	213.08	193.17	172.69
	M24. late					
Soybean Yield	Bu/ac	28.67	28.72	28.7	28.67	28.67
Wheat Yield	Bu/ac	58.67	58.4	58.47	58.67	57.52
Corn Yield	Bu/ac	125.52	125.48	125.49	125.52	123.06

Where A26 = sowing data of April 26^{th}, S27 = sowing date of September 27^{th}, A05 = sowing date of April 5^{th}, A19 = sowing date of April 19^{th}, mg4 = plant variety 4 for soybeans, mg3 = plant variety 3 for soybeans, mg5 = plant variety 5 for soybeans, .late = plant variety late for corn.

Table 3.6: Production Results of a Hypothetical Ohio Valley Farm for Lightbar Adoption Sensitivity Analysis Under Medium Risk Aversion

			Medium Risk Aversion Lightbar w/o			
		All Lightbar Benefits	Time Req	Labor Cost Req	Input Cost Req	Yield Benefits
Double Crop Soybeans	S27. MG3	347.45	339.15	348.96	374.45	373.22
	S27. MG4	211.81	202.96	205.71	211.81	204.26
	S27. MG5	1.04			1.04	97.52
	O04.MG4					
	O04.MG5					
	N22.MG5	87.71	132.88	120.33	87.71	
Wheat						
Corn	A26. late	66.03	133.86	119.42	66.03	71
	Ao5. late	474.35	437.86	448	474.35	474.35
	A19. late	120.05	103.27	107.58	120.05	129.65
	M24. late	14.57			14.57	
Soybean Yield	Bu/ac	29.17	29.48	29.4	29.17	29.24
Wheat Yield	Bu/ac	56.6	55.26	55.63	56.6	55.2
Corn Yield	Bu/ac	125.52	125.49	125.5	125.52	123.07

Where A26 = sowing data of April 26^{th}, S27 = sowing date of September 27^{th}, A05 = sowing date of April 5^{th}, A19 = sowing date of April 19^{th}, mg4 = plant variety 4 for soybeans, mg3 = plant variety 3 for soybeans, mg5 = plant variety 5 for soybeans, .late = plant variety late for corn.

Table 3.7: Production Results of a Hypothetical Ohio Valley Farm for Lightbar Adoption Sensitivity Analysis Under High Risk Aversion

			High Risk Aversion Lightbar w/o			
		All Lightbar Benefits	Time Req	Labor Cost Req	Input Cost Req	Yield Benefits
Double Crop Soybeans	S27. MG3	325.5	295.12	303.56	324.01	325.95
	S27. MG4	50.95	78.52	70.87	49.91	44.87
	S27. MG5					
	O04.MG4					
	O04.MG5					
	N22.MG5	195.25	196.32	196.02	192.43	206.17
Wheat		103.29	105.04	104.55	108.66	98
Corn	A26. late					
	Ao5. late	370.56	433.82	416.25	370.24	361.86
	A19. late	304.44	241.18	258.75	304.76	313.14
	M24. late					
Soybean Yield	Bu/ac	30.15	30.17	30.18	30.15	30.23
Wheat Yield	Bu/ac	53.41	53.38	53.39	53.5	52.05
Corn Yield	Bu/ac	125.4	125.47	125.45	125.4	122.93

Where A26 = sowing data of April 26th, S27 = sowing date of September 27th, A05 = sowing date of April 5th, A19 = sowing date of April 19th, mg4 = plant variety 4 for soybeans, mg3 = plant variety 3 for soybeans, mg5 = plant variety 5 for soybeans, .late = plant variety late for corn.

Chapter Four

Conclusions

This thesis has examined farm management practices in an attempt to improve farm profitability. It has done so through two separate, yet complementary scientific articles; one addressing cost maps and the other the use of lightbar technology. An underlying theme of assessing farm management practices in an effort to increase expected net returns while reducing risk has been present throughout this thesis. This theme allowed me to look at the topic of precision agriculture in two regards: lightbar, and cost maps. The topic of lightbar is part of the vernacular among precision farmers today. Cost maps, however are an idea that is less talked about and whose benefits are still yet to be realized. Both show supportive results that they have to ability to not only help farmers in increasing profits but also have the ability to possibly to reduce risk as well.

The first manuscript explores production cost maps as a tool for improved farm management. The need for the study arose from the primary equation of marginal revenue equaling marginal costs. While yield is a good representation of marginal revenue, single inputs such as fertilizer needed to be expanded to incorporate more fully all marginal costs. This expansion is represented in the form of the total variable cost map derived in Chapter 2. The discussion utilized the collection of information gathered from machines while in operation to visually depict cost maps associated with those machines. The cost maps show that skips and overlaps in application of inputs as well as going back to get missed sections of a field are very costly. An analysis of the cost maps allows for new management decisions such as to produce or not to produce, CRP enrollment, and optimal path determination. These management decisions may be directly impacted by observing the total variable cost map and interpretation of the data. A recommendation that the cost maps suggest is that skips, overlaps and extra passes in the field have great cost. In an attempt to reduce these costs, guidance aides as well as a properly planned path is suggested.

The second article, examines how lightbar under a whole farm model influences the profitability of a hypothetical farm. The technology of lightbar has been studied under enterprise partial budgets but the study of lightbar under the whole farm model proves to be beneficial. While lightbar demonstrates an increase in expected net returns this study also reflects the potential for risk reduction shown by the coefficient of variation. Sensitivity analysis was performed on this model to look at different situations that may occur. It is shown that by adding lightbar and all the influences attributed with it, farm profitability goes up as well as the possibility for risk reduction. The biggest contribution that lightbar affords in a financial aspect is the yield increase, although the yield increase could not be fully realized without the ability to switch planting and harvesting dates as well as alternate between enterprises. A recommendation of this study is for the adaptation of lightbar technology, provided that the farm acreage is in excess of 44.5 acres.

The results from this thesis are encouraging in the fact that they show improvements which farmers can make to existing farms to increase profits and reduce risk, but there are some considerations to be made. This is a very comprehensive study which took years in acquisition of data and analysis. Farmers may not have the luxury to complete a study of this size and scope and therefore the principles and/or the results of this study may be applied to their individual farming situations. That is where the state of Kentucky excels in its communication between researchers and farmers. Kentucky has an Extension Service available to all farmers in each 120 counties, whose mission is to make a difference in the lives of Kentucky citizens through research-based education. The Extension Service takes the University to the people in their local communities, addressing issues of importance to all Kentuckians. This Extension Service has agents that are well trained in the field of agriculture and are in close contact with the farmers of the State. This is the link that researchers have between conception and implementation. With the help of the Cooperative Extension Service theories that were only tested on paper can now be brought to the public.

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Vita

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